

Co-benefits approach: Opportunities for implementing sponge city and urban heat island mitigation

Bao-Jie He^a, Jin Zhu^{a,*}, Dong-Xue Zhao^b, Zhong-Hua Gou^c, Jin-Da Qi^a, Junsong Wang^d

^a Faculty of Built Environment, University of New South Wales, NSW, 2052, Australia

^b School of Biological, Earth and Environmental Sciences, University of New South Wales, NSW, 2052, Australia

^c School of Engineering and Built Environment, Griffith University, QLD, 4215, Australia

^d School of Architecture, State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, Guangdong, 510640, China

ARTICLE INFO

Keywords:

Sponge city
Urban flooding management
Urban heat island
Co-benefits approach
Synergy effect
Mitigation strategies

ABSTRACT

Climate change and its impacts cannot be addressed once for all due to internal complexity. Some implemented strategies may only be capable of dealing with a cluster of problems while leaving many others untouched. The co-benefits approach, however, opens up a 'window of opportunity' via achieving multi-goals simultaneously. Based on this, this paper aims to unpack the interrelationship between the struggling urban heat island (UHI) issue and the already ongoing sponge city (SPC) projects in China. Specifically, the co-benefits are investigated from technical, financial, institutional and social perspectives, after which pathways to implementation are presented. In these aspects, the co-benefits approach can bring opportunities for implementing SPC and UHI mitigation. The inclusion of UHI mitigation into SPC construction can enhance public participation and thereby consolidate the public-private partnership model for funds. During the co-benefits approach implementation, the weights of different authorities can be rebalanced to promote institutional transitions. SPC-derived UHI mitigation approach, potentially realising synergies of urban flooding and UHI mitigation, can be a model for countries which have already released low-impact development water management practices, and may also provide references for other projects such as green building, low-carbon eco-city, smart city, forest city and haze treatment for UHI mitigation.

1. Introduction

Human beings' extensive transformation towards the natural environment has led to various natural hazards. Climate change, as one of the fundamental impacts, is posing severe threats to the livelihoods and assets of human themselves, so that people are enlightened to consider approaches to climate change mitigation and adaption. However, climate change is too formidable to develop omnipotent/universal plans for mitigation and adaption. Alternatively, some simple and inexpensive measures have been adopted (World Bank, 2011), but these 'no regret' strategies can just provide a short-term solution to climate change, and cities cannot get rid of the risks of climate change and present more vulnerabilities in the long run (Conway and Schipper, 2011). Nevertheless, some severe problems have been prioritised by municipalities for mitigation with the input of special funds. The mitigation of these problems can bring some unintentionally positive benefits to alleviate other issues, as the phenomenon called co-benefits of climate change mitigation (IPCC, 2007).

The co-benefits approach is considered as a win-win strategy to address two or more issues. Regarding the climate change issue, numerous investigations have devoted to identifying co-benefits opportunities existing plans, policies and projects can offer (Nemet et al., 2010; Harlan and Ruddell, 2011; Balbus et al., 2014) to motivate unimplemented actions and achieve the synergies of various sustainable initiatives in different dimensions (Bain et al., 2016; He et al., 2018). Co-benefits of already implemented commitments cover various scopes ranging from greenhouse gas (GHG) reduction and city resilience to economic, social, environmental and institutional benefits (Mayrhofer and Gupta, 2016). However, co-benefits are not easy to realise because of the significant differences in respective mechanisms and requirements of different projects. This affirms the value of understanding the resources that are required to implement one strategy and at the same time benefit another. With better understandings of the relationships between different projects and the co-benefits approach as well as a clearer intention, the positive impacts can be achieved and even amplified, as shown in Fig. 1.

* Corresponding author.

E-mail addresses: baojie.he@unsw.edu.au (B.-J. He), jin.zhu@unsw.edu.au (J. Zhu).

<https://doi.org/10.1016/j.landusepol.2019.05.003>

Received 30 May 2018; Received in revised form 27 April 2019; Accepted 1 May 2019

0264-8377/ © 2019 Elsevier Ltd. All rights reserved.

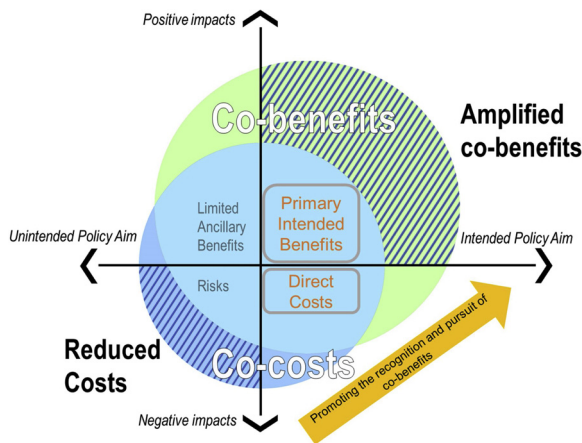


Fig. 1. Schematic map of co-benefits evolution from unintended to intended policy aim.

In cities, urban flooding and temperature increase are two typical concerns of climate change (World Bank, 2011). During urbanisation, urban surfaces are continuously modified towards impervious from pervious (Zhao et al., 2017). Subjected to heavy precipitation, cities cannot drain excessive water in a short time, thereby under the risks of urban flooding or waterlogging (Hu et al., 2018). The urban surface flooding is one of the severest disasters leading to hazards to human lives, transport, housing and other infrastructures, especially for highly urbanised and populated megacities during rainy seasons (Chan et al., 2018). Another apparent manifestation of the climate change is the increasing urban temperature, known as urban heat island (UHI) causing a dramatic increase in morbidity and mortality, energy consumption and agricultural losses (Zhao et al., 2018; Qi et al., 2019). Both urban surface flooding and UHI phenomenon will be further aggravated (Chan et al., 2018; He, 2018) with the ongoing urbanisation.

Many city officials have developed plans, policies and projects to mitigate the urban surface flooding, such as the low-impact development (LID, US and Canada), sustainable urban drainage systems (SUDS, UK), blue-green cities (BGC, UK), water sensitive urban design (WSUD, Australia and the Middle East), and low impact developments urban design (LIDUS, New Zealand) (Li et al., 2016). Comparatively, the problem of UHI has received less attention. It is understandable that water management and flood control become the priority of cities because of more direct threats to the operation of cities and people's normal life when compared to UHI. However, it is also the time to take effective measures to mitigate UHI effects.

Some studies have indicated that urban flooding management (UFM) strategies are always versatile, with high possibilities of co-benefits on other fields, like recreation and aesthetics, water quality improvement and water supply, as well as UHI mitigation (UHIM) (Fletcher et al., 2015; Jiang et al., 2018; Liu et al., 2017). However, the co-benefits of UFM on UHIM has not been well explained yet. For advancing the co-benefits for UHIM, therefore, it is essential to examine the feasibility to include UHIM into UFM.

Therefore, this paper aims to unfold the interrelationship between UHIM and the ongoing UFM projects, so as to highlight the co-benefits of these two projects for further policy-making. Although studies have indicated the co-existence of co-effects, co-impacts, co-costs, ancillary impacts and life cycle impacts (as presented in Fig. 1), we only focus on the co-benefits, the synergetic objectives, to narrow down the macro-scope in connection with co-benefits, thereby proving a comprehensive landscape of understanding. This study is particularly contextualised in China to elaborate the co-benefits of a top-down UFM project known as sponge city (SPC) on UHIM. To complete this paper, the following section demonstrates the methodology adopted in this study, in which a brief overview of SPC and UHIM regarding their current situations,

policy implementations and financial supports is presented. Section 3 analyses the interdependency between SPC implementation and UHIM. Section 4 discusses the pathway to the implementation of co-benefits in terms of status, multi-level multi-stakeholder framework and practical approaches to advancing co-benefits. Finally, Section 5 concludes this paper. Overall, this study will inform policy-makers with a comprehensive understanding of how to advance the co-benefits and even realise the synergies between UFM and UHIM.

2. Methodology

2.1. Study context

China adopted the 'hard-path' UFM approach, with the construction of massive infrastructures like dams/reservoirs with dykes, river channel management, flood diversion zones (Liu et al., 2013). Since 1950, China has constructed more than 97,000 dams and 98,000 reservoirs, 46,758 hydropower stations, 268,476 water gates, 413,679 km of dikes and 424,451 pumping stations (MWR, 2013). These hard-engineering control measures are effective in addressing fluvial or riverine floods from upstream catchment areas (Chan et al., 2018). However, these measures are not that adequate in cities (Chan et al., 2018). During intense rainfall, the over-reliance of traditional drainage systems for flood protection underperforms and leads to urban flooding or waterlogging.

Between 2008 and 2010, 214 among 351 cities underwent waterlogging, 137 cities underwent at least three times annually, and 57 cities were submerged for many than 12 h (Li et al., 2016). The accumulative water in cities further deteriorates after a long time, polluting urban water sources. Moreover, the traditional 'fast-draining' approach that discharges the rainwater out cities, aggravating the severity of water scarcity. It is essential to seeking new ecologically appropriate alternatives to the mitigation of water problems including urban flooding, water pollution and water scarcity (Hu et al., 2018).

Since the 'Reform and Opening Up' policy in 1978, China has witnessed rapid urbanisation accompanied by extensive densification and urban sprawl. Unfortunately, continuous modifications of natural surfaces (i.e., water bodies, trees and agricultural lands) towards artificial structures (i.e., buildings and roads) have caused various ecological issues, of which UHI has been the most prominent one posing severe pressure to urban systems and ecosystems. Nevertheless, either temporal or spatial investigation on the UHI evolution has indicated China has been undergoing an aggravated UHI phenomenon (He et al., 2019; Zhou et al., 2014; Yang et al., 2019), so that it is urgent to formulate planning policies and regulations for UHIM (Peng et al., 2019).

2.2. Implementation of SPC and UHIM in China

To address the problem of urban flooding, the central government of China proposed the advocacy of SPC, with which urban surfaces could absorb, store, seep and purify water, and further release stored water for use when necessary (MOHURD, 2014). The SPC can potentially overcome the drawbacks of the traditional drainage networks and widely-applied concrete surfaces, such as reductions in porous surfaces and rainfall infiltration, water storage and underground water recharge (Xia et al., 2017; Chan et al., 2018). In long-term duration, SPC can further coordinate the conformity among natural precipitation, surface water and groundwater, and consort all aspects of water recycling, water supply and water drainage (MOHURD, 2014). Moreover, SPC proscribes three requirements of original ecosystem protection, ecological recovery and restoration and LID to highlight the protection and improvement of urban ecological environments (Table 1).

After SPC proposition, a series of national policies have been released successively. In 2014, the MOHURD released the 'Construction guideline of sponge city in China—low impact development of the stormwater system (trial)'. It provides principles for SPC construction and clarifies

Table 1
Primary requirements of the pathway to the SPC. (MOHURD, 2014).

Provision	Requirements
Protecting the original ecosystems of cities	● Maximise the protection of existing water-physiological sensitive areas such as rivers, lakes, wetlands, pit ponds, ditches, etc; ● Preserve sufficient forests, grasslands, lakes and wetlands to conserve water sources and address intense rainfall; ● Maintain the original characteristics of natural hydrology.
Ecological recovery and restoration	● Utilise ecological means to recover and restore the damaged water bodies and other natural environments due to traditional extensive urban development pattern; ● Maintain a certain proportion of ecological space.
LID	● Reasonably control the development intensity; ● Retain sufficient ecological lands in urban areas; ● Constrain the proportion of impervious area in cities; ● Minimise the damage to urban original water ecological environment ● Properly excavate rivers and lakes and ditches and increase the water area for water storage, infiltration and purification.

primary techniques in different stages. It specifies permeable pavements, green roofs, sunken green space, bio-detention facilities, osmotic pools, seepage pits, wet ponds, rainwater wetlands, cisterns, rainwater tanks, regulating ponds and pools, grass-planting ditches, infiltration pipes/canals, vegetation buffer, rainwater disposal facilities and artificial soil infiltration (MOHURD, 2014), to realise functions of infiltration, detention, storage, purification, reuse and drainage. To support these techniques, various codes and standards have also been enforced to guarantee their application in SPC design and construction, as shown in Table 2.

Moreover, the guideline plays a significant role in delivering national advocations to local communities, as it practically (i) instructs planners on how to implement LID philosophy in SPC construction; (ii) guides the design, implementation and maintenance of facilities for the LID of new, existing and expansion projects, and; (iii) directs departments that are responsible for urban planning, drainage, road traffic and gardens to guide and supervise the practical construction of SPC (MOHURD, 2014). With the guidance of the national guideline, more than 130 cities have accordingly developed local schemes to construct SPC.

In support of SPC construction, the Ministry of Finance (MOF) announced the ‘*Notice on financially supporting pilot SPC projects by the Central Government*’ in 2014. Afterwards, the MOF, MOHURD and MWR (Ministry of Water Resources) collaboratively set up special funding for 30 national pilot cities in two rounds, as shown in Table 3. Each city received 1.2–1.8 billion RMB in total in three consecutive years, and public-private partnerships (PPP) are given financial subsidies (Jia et al., 2017). Many provinces have also established special funds to construct provincial SPC pilot projects. In 2016, the provincial level government entities, including Housing and Construction, Finance, and Water Resources, jointly organised the review of provincial SPC projects, as shown in Table 3. The central government also encourages the pilot cities and local governments to explore innovative approaches to more funds, such as the PPP, tax-increments, development charges, value-capture taxes, loans, and bonds according to local conditions (Li et al., 2017).

Moreover, both central and local governments have drawn on the significance of dissemination and public participation. In both national and local SPC promotion plans, it has been proscribed that the governments should make detail plans to raise public awareness of SPC. Meanwhile, citizens should be informed with the role of SPC in ecological environment, facilities function and quality of life, so as to increase the social and create a good construction atmosphere. Many cities have actively publicise SPC by the means of publications (press release, e-newsletter and articles), market events (Presentations, catalogues, tender), social media (Wechat, QQ), training sessions, newspapers, local TVs and radios, scientific conferences, workshops and seminars, other materials (leaflet, brochure, poster and banners)¹.

Comparatively, on the issue of UHIM, there have been some ideas on climate-sensitive techniques and strategies, such as greening system, cool materials, water bodies and urban ventilation. It is also pointed out the urban construction should adapt to meteorological characteristics and synoptic conditions (He, 2018). However, the implementation of these techniques has been hindered by the evolving built environment and urban expansion, a manifestation of ongoing urbanisation. There are very fragmented plans for UHIM, so that UHIM has to follow some very general policies for climate change such as the white paper for population, environment and development, China Agenda 21 and the efforts made for low-carbon and climate-adaptive development (NDRC, 2017, p. 3–4):

- Mitigation and adaption of climate change
- Local and industry action, and public participation
- Planning and institutional development
- Basic capacity building
- International exchange and cooperation
- Participation in global climate governance

Although these measures can yield co-benefits for UHIM, they may also aggravate uncontrolled UHI. Moreover, these measures are sensitive to economic development, especially in developing countries. In particular, although economic structure transitions and energy efficiency improvement have been well respected, upgrading the industrial structure has to make concessions to economic development (Mayrhofer and Gupta, 2016). Therefore, the policies for UHIM should be proposed explicitly.

2.3. Linkages between SPC and UHIM

Cities are encountered with various problems that may be related to energy efficiency, public health security, weather monitoring and warning, infrastructure planning and design, etc. To address these problems, specific plans are always implemented separately. Many of them can also generate mitigating effects on other fields. For UHIM, it also receives benefits from many other projects. For instance, the ‘National Forest City’ that aims to promote forestry growth can benefit UHIM through improving urban ecology and enhancing public participation in urban greening. To construct of low-carbon eco-city, many cities have underlined the necessity of UHIM in aspects of land use pattern, urban greenery, building coating, low-carbon technologies and the coordination of urban-rural planning. For the SPC implementation, it can technically generate the benefits to UHIM. It is reported that Changde, Hunan Province, embarked SPC construction from 2014 and

(footnote continued)

sohu.com/a/246092462_100188353; <https://jiaxing.19lou.com/forum-778-thread-162661530803772433-1-1.html>; http://www.spongerain.com/news_detail/newsId=897.html.

¹ Different means of publicisation are applied by municipalities: <http://www.>

Table 2
The specifications, codes and standards for SPC design and construction.

Stage	Innovative techniques	Specifications, codes and standards
Design	Non-traditional water utilisation	Assessment standard for green building (GB/T50378)
	Green roof	Technical code for roof engineering (GB/T 50345-2012)
	Urban rainwater pipes and pumping stations	Code for design of outdoor wastewater engineering (GB 50014-2006)
	City road	Code for design of urban road engineering (CJJ37-2012)
	Green space in urban park	Code for the design of public park (GB 51192-2016)
Construction	Urban water system	Code for design of urban flood control project (GB/T 50805-2012)
	Permeable pavement	Technical specification for the pavement of water permeable brick (CJJ/T188-2012)
		The technical specification for permeable asphalt pavement (CJJ/T 190-2012)
		The technical specification for pervious cement concrete pavement (CJJ/T 135-2009)
		The technical specification for the green roof (JGJ 155-2013)
	Green roof	National standard atlas: Comprehensive utilisation of rainwater (10SS705)
	Reservoir	Manual for water supply and drainage design
	Regulation pool	

Table 3
The national and provincial SPC pilot projects in China.

Level	Year	Cities
National level	2015 (1 st round)	Qian'an, Baicheng, Zhenjiang, Jiading, Chizhou, Xiamen, Pingxiang, Jinan, Hebi, Wuhan, Changde, Nanning, Chongqing, Suining, Gui'an New District, Xixian New District
	2016 (2nd round)	Beijing, Tianjin, Dalian, Shanghai, Ningbo, Fuzhou, Qingdao, Zhuhai, Shenzhen, Sanya, Yuxi, Qingyang, Xining, Guyuan
Provincial level	Henan 2016	Zhengzhou, Luoyang, Pingdingshan, Anyang, Jiaozuo, Fuyang, Xuchang, Shangqiu
	Anhui 2016	Hefei, Zhangzhou, Handan, Zhangzhou, Wuhu, Xuancheng, Tongling, Anqing, Huangshan, Wuhu, Nanling, Qixian, Qianshan, Quanjiao, Susong
	Shaanxi 2016	Baoji, Tongchuan
	Jilin 2016	Changchun, Siping, Tonghua, Yunchun
	Yunnan 2016	Kunming, Dali, Qujing, Lijiang, Chuxiong,
	Guangxi 2016	Liuzhou, Guilin, Beihai, Fangchenggang, Yulin, Baise
	Zhejiang 2016	Shaoxing, Quzhou, Lanxi, Wenling
	Hunan 2016	Yueyang, Jinshi, Wangcheng District, Fenghuang County
	Shandong 2016	Weifang, Tai'an, Linyi, Liaocheng, Binzhou, Qingzhou, Qufu, Jixian
	Sichuan 2016	Chengdu, Zhangzhou, Zigong, Mianyang, Guang'an, Chongzhou, Qixian, Jiangyou, Pengxi, Xichong, Huaying, Dazhu, Pingchang, Anyue, Xichang
	Jiangsu 2017	Wuxi, Suqian, Lianyungang, Xinyi, Jingjiang

its UHI intensity in 2016 was 0.92 °C lower than that in 2013, indicating the potential of SPC to UHIM.

From the perspective of co-benefits, the benefit of a project to another one not only lies in science, technical or environmental dimension, the benefit can also be found in social, economic, political/institutional and climate-related dimensions, as shown in Fig. 2 (Mayrhofer and Gupta, 2016). The co-benefits in the economic dimension can be performed as attracting private investment, improving economic performance, contributing to fiscal sustainability. For the social dimension, co-benefits could be poverty reduction, energy access enhancement, water security warranty and its health implications. In a

political and institutional aspect, co-benefits can behave as political stability contribution, governance improvement and better inter-regional collaboration. Both SPC and UHIM are projects covering several different departments and units, but they have their own focuses during urban construction, implying they do not essentially prioritise UHIM. Moreover, the lack of coordination among various authorities has constrained the promotion of urban greenery and water system and the policy effect. Besides the fragmented administration, technical guidance, public financing and economic incentives, as well as education and training to promote urban greening and water system, have not been presented (Jia et al., 2017). To eliminate the institutional

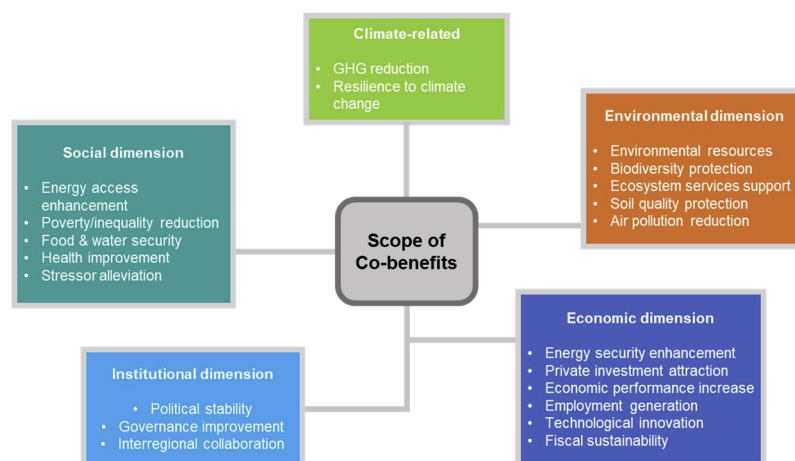


Fig. 2. Scopes of co-benefits in five dimensions at three levels (Adapted from Mayrhofer and Gupta, 2016).

barriers to UHIM and SPC, the co-benefits among SPC and UHIM should be elaborated.

2.4. Co-benefits transitions among multi-scale multi-stakeholders

For SPC, the existing guidelines and policies can be flags for different governmental departments and societal participation, while UHIM has not been prioritised practically. Co-benefits approach is capable of transferring the horizontal overlaps that are included in SPC for UHIM. Conversely, addressing a synergistic system for SPC and UHIM can also bring various benefits to SPC as many risks and uncertainties still exist in every stage of SPC implementation (Li et al., 2017). Therefore, in dealing with SPC and UHIM simultaneously, it is essential to develop a framework to realise co-benefits implementation among multi-scale multi-stakeholders.

Implementation of co-benefits approach for SPC and UHIM can be regarded as a transition process of a specific social-technical system so that this study will understand its promotion process from the perspective of multi-level perspective (MLP). The MLP approach consists of three analytical levels of niche (micro), regime (meso) and landscape (macro), where radical innovations at niche level can motivate the whole changes of social-technical landscapes (Geels, 2002). Apart from vertical integrations, it can cover two or more different projects in the horizontal dimension because of the existence of commonalities (He et al., 2018). For the co-benefits of SPC and UHIM, it should vertically evolve from community to city and regional level and horizontally indicate the linkages between SPC and UHIM.

3. Recognition of co-benefits between SPC and UHIM

3.1. Necessity to implement the co-benefits approach

Cities are under the threats of climate change which has greatly hastened human beings to take effective measures. Conducting these mitigation and adaption activities requires citizens' actions in economic payment and the transitions in awareness and behaviours, which becomes a barrier to the actions of most governments. Co-benefits can not only maximise the potentials of existing strategies to support innovation, deliver economic benefits and enhance living quality, but also enhance citizens' behaviours to support and follow governments' actions to climate change mitigation and adaption (Floater et al., 2016). Therefore, the co-benefits approach has increasingly developed into a major topic in the decision-making process of climate change (Ürge-Vorsatz et al., 2014). It will also be a pattern to address the two major problems of urban flooding and UHI in Chinese cities.

On the one hand, the UHIM is mainly advocated in academic scope, with the identification of effective UHIM strategies of cool material, urban greenery, water bodies and reasonable urban modifications. Some cities start to prioritise UHIM. However, there are no specific and comprehensive plans for UHIM, but some partial cool roof projects or even some projects that can generate partial benefits such as green building, forest city, low-carbon eco-city, etc. Nevertheless, the current trend that has to be noticed is that urban temperature will continuously increase along with the ongoing urban development. Therefore, UHIM should be urgently and, more importantly, cost-effectively implemented, in which situation co-benefits approach should be highlighted.

On the other hand, although central and local governments have respectively established technical guideline, financial incentives, political/institutional support and social dissemination, there still exists various barriers in technology, physical situation, finance, standard and regulations, social acceptance, inter-department cooperation and data sharing, as shown in Fig. 3 (Li et al., 2017). These barriers are always intertwined, increasing the complexity to address them. For 30 pilot cities in China, for example, technical barriers have significantly elevated economic investments. It is estimated that implementing each

square kilometre of SPC costs 0.10–0.15 billion RMB, meaning national incentives can support 30–40 square kilometre SPC in each city (MOHURD, 2015). To deal with the economic budget, it is essential to include financial support for the general public, while the public participation rate is still low, because of the non-involvement of propaganda departments, pulling down the opportunities to attract societal investments. Meanwhile, the improper geographic location, land scarcity and lack of collaboration among different agencies have enhanced the difficulties to build SPC simultaneously. This affirms the importance to implement the co-benefits approach when addressing risks and uncertainties in SPC implementation.

3.2. Feasibility to implement the co-benefits approach

3.2.1. Technical/Environmental feasibility

UFM has been evolving in its scientific understandings continuously since the urban drainage system was adopted (Fletcher et al., 2015). Apart from flood mitigation, the urban stormwater management has been designated to enhance recreation and aesthetics, to improve water quality and supply water, as well as to regulate microclimate, along with the climate change and urbanisation (Jiang et al., 2018). For the co-benefits of SPC for UHIM, techniques adopted for SPC construction mostly fall into green infrastructures or blue infrastructures (as shown in Table 4), apparently delivering additional benefits in aspects of urban greening, eco-system enhancement, public health upgrading, air quality improvement and UHIM. Furthermore, most techniques can be utilised in the context of building and neighbourhood, road system, and green space and square, which highlights their suitability in mitigating UHI effects of areas citizens use frequently.

From the perspective of land use/land cover, SPC construction is a process to modify urban surface from impervious to pervious one. The porous brick, porous concrete pavement, porous asphalt pavement and green roof that are adopted to accomplish the infiltration function (Table 4), are also robust to lower surface temperature. For permeable pavements, the surface temperature of porous bricks and porous concrete can be 10 °C lower the normal brick and concrete pavements, and the air temperature can be reduced by up to 1 °C (Wang et al., 2019). The vegetation of the green roof system can capture much of the precipitation and the water evaporates from soil surfaces into the atmosphere by transpiration. At the same time, the transpiration reduces the surface and air temperature via the latent heat release. It is shown that the green roof can lower the average ambient temperature between 0.3 and 3 °C at the city scale (Santamouris, 2014).

Other techniques like sunken green space, simple bio-detention facility, complex bio-detention facility, transmission type grass-planting ditch, dry grass-planting ditch, wet grass-planting ditch and vegetation buffer fall into the scope of green infrastructures (Table 4), whose UHIM effects have been also evidenced (Norton et al., 2015; Emmanuel and Loconsole, 2015; Herath et al., 2018; Yang et al., 2017). For the osmotic pool, wet pond, rainwater wetland and regulating pool and pond can be regarded as blue infrastructures that have apparent cooling effects on UHI. It is shown that urban wetlands have the capability to reduce urban air temperature by 1–2 °C (Manteghi and Remaz, 2015). The water pools and ponds can reduce the city air temperature between 0.1 and 1.9 °C, and the maximum air temperature reduction can reach 7.1 °C (Santamouris et al., 2017). For the surface temperature, the blue infrastructures can be 9.2 °C lower than building temperature (Zhao et al., 2017). Therefore, blue infrastructures have the greatest capability to mitigate UHI effects. For others like seepage pit, infiltration canal and artificial soil infiltration can also benefit UHIM.

Overall, the SPC construction and UHIM are technically compatible and the SPC individual facilities presented are flexible in their suitability and configuration to urban planning requirements and water system characteristics. Therefore, in real practice, the possible limitations of adopting these technologies for UHIM can be minimised. Facilities on the blue infrastructure should be constructed in a

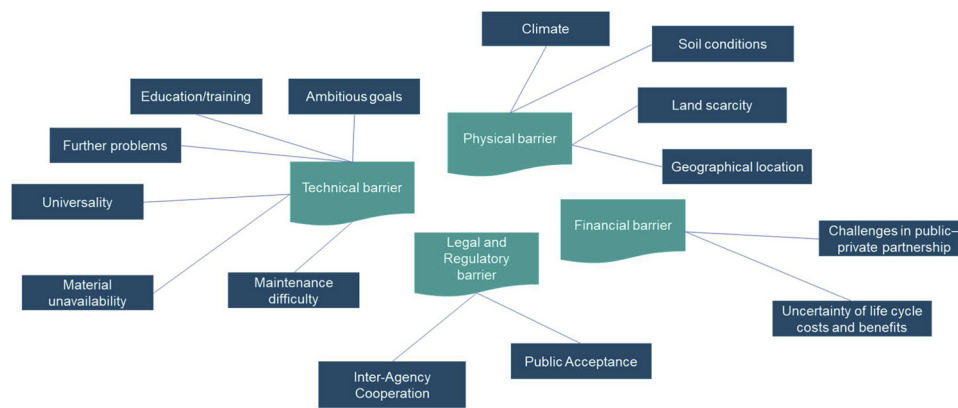


Fig. 3. The barriers identified in SPC construction (Adapted from Li et al., 2017).

concentrated way, which does not compress the space people required for daily activities. Other strategies can be implemented over scattering spaces, which are favourable for daily usage. All these individual facilities exhibit excellent suitability in building and neighbourhood, road system, green area and square and water system, meaning that the SPC can be universal to mitigate UHI, rarely restricted by the specific locations. Moreover, road system heat mitigation is mostly dependent on reflective materials or porous materials, while SPC presents a series of viable techniques, instructing engineers and planners with more choices.

3.2.2. Financial feasibility

In response to the increasing urban temperature, citizens' adaptive

behaviours lead to the increase in energy and water use. Nevertheless, temperature is sometimes higher than the bearable level, resulting in excessive mortality (Santamouris et al., 2017). The heat-related morbidity is much more apparent affecting people, generating large public health costs (Harlan and Ruddell, 2011). UHIM, therefore, can directly generate benefits in environmental and social aspects on the one hand and have profitable economic benefits on the other. A study in Phoenix, Arizona, USA indicates that a 5 per cent increase in urban vegetated areas can reduce the annual electricity use in 1553.2 GW h, corresponding to 155.32 million US dollar in cooling bills (Silva and Fillpot, 2018). For an area with 99,440 m² green roof installation in the Aegean region of Turkey, the energy saving can reach 2188 US dollar on a daily basis (Çelik et al., 2010). Moreover, UHIM strategies including Cool

Table 4

Comparison of SPC facilities in UHI mitigation, suitability, layout and economic cost. (Revised based on MOHURD, 2014). (For interpretation of the references to colour in this table, the reader is referred to the web version of this article.)

Function	Individual facilities	UHI mitigation strategies			Horizontal scale				Layout		Economic cost	
		Cool pavement	Green infrastructure	Blue infrastructure	Building and neighbourhood	Road system	Green space and square	Water system	Scattered	Concentrated	Construction	Maintenance
Infiltration	Porous brick	●	○	○	●	●	●	●	√	○	Low	Low
	Porous concrete pavement	●	○	○	●	●	●	●	√	○	High	Medium
	Porous asphalt pavement	●	○	○	●	●	●	●	√	○	High	Medium
	Green roof	○	●	○	●	○	○	○	√	○	High	Medium
	Sunken green space	○	●	○	●	●	●	●	√	○	Low	Low
	Simple bio-detention facility	○	●	●	●	●	●	●	√	○	Low	Low
	Complex bio-detention facility	○	●	●	●	●	●	●	√	○	Medium	Low
	Osmotic pool	●	○	●	●	●	●	○	○	√	Medium	Medium
	Seepage pit	●	○	○	●	●	●	○	√	√	Low	Low
Storage	Wet pond	●	○	●	●	●	●	●	○	√	High	Medium
	Rainwater wetland	●	○	●	●	●	●	●	√	√	High	Medium
	Cistern	○	○	○	●	○	●	○	○	√	High	Medium
	Rainwater tank	○	○	○	●	○	○	○	√	○	Low	Low
Regulation	Regulating pond	●	○	●	●	●	●	●	○	√	High	Medium
	Regulating pool	○	○	●	●	●	●	○	○	√	High	Medium
Transfer	Transmission grass-planting ditch	○	●	●	●	●	●	●	√	○	Low	Low
	Dry grass-planting ditch	○	●	●	●	●	●	●	√	○	Low	Low
	Wet grass-planting ditch	○	●	●	●	●	●	●	√	○	Medium	Low
	Infiltration pipe/canal	●	○	○	●	●	●	○	√	○	Medium	Medium
Purification	Vegetation buffer	○	●	○	●	●	●	●	√	○	Low	Low
	Rainwater disposal facility	○	○	○	●	○	○	○	√	○	Low	Medium
	Artificial soil infiltration	●	○	○	●	○	●	●	○	√	High	Medium

Note: ● means good; ● means general; ○ means not good, or no; ○ means indirect impact; √ means yes.

materials, green and blue infrastructures are economically attractive after the payback period (Peng and Jim, 2015). However, the once payoff and considerable initial construction investments at the city scale have anecdotally comprised the local governments' enthusiasms to disseminate and implement them (Henry and Frascaria-Lacoste, 2012).

Comparatively, 30 national and more provincial SPC pilot projects have been financially supported by national and provincial governments, enabling local governments to exploratively construct SPC. This simultaneously lays the economic foundations to connect the UHIM with the SPC construction, when considering the high compatibility among the techniques for SPC construction and UHIM. Every square kilometre construction of SPC costs as much as 0.1–0.15 billion RMB, while the investment is sufficient to implement effective UHI mitigation and adaption strategies. This indicates the feasibility to synergistically eliminate the economic barrier to UHIM implementation. According to the economic cost in Table 4, after paying for the initially medium and high construction costs of most techniques, the maintenance costs fall back to low and medium levels. This indicates that pre-investment with the support from the national government in SPC will not leave heavy financial burdens for local governments in dealing with UHIM.

The government encourages innovative approaches to more funds for SPC construction. The extensive dissemination has been emphasised for the improvement of public awareness. The PPP model and dissemination are beneficial to raise funds among the public and to enhance their participation, which is stable for future economic investments (Wang et al., 2017). Nevertheless, the PPP model in China has been criticised because of lack of information on PPP, lack of institutional capacity, absence of specific SPC plan and no specific regulation for PPP management (Li et al., 2017; Wang et al., 2017). This is because many suppliers, stakeholders and the public are reluctant to support an emerging pilot project. As pointed out, the implementation of the co-benefits approach is capable of enhancing public participation to follow governmental actions to climate change, thereby the opportunities to attract private investment (Bain et al., 2015). Based on this, the inclusion of UHIM, namely improving the thermal environment that most people are daily suffering from, can resonate with people, being a motivation for the participation of the general public. Overall, the SPC construction brings co-benefits to UHIM in funds, and UHIM consolidates SPC implementation in public participation.

3.2.3. Institutional feasibility

Although the UHIM is increasingly becoming an independent topic in urban climate studies, the strategies and techniques adopted for UHIM are interdisciplinary across many distinct authorities. The promotion, implementation and maintenance of green infrastructures are the responsibilities of forestry, gardening and landscaping bureaus. In comparison, the water affairs bureau plays roles in promoting blue infrastructure utilisation. The road, traffic and construction bureaus concern the implementation of cool pavements. In addition, the planning, land and resource departments are responsible for planning-making. Overall, the practical UHIM is a complex issue concerning various administrative authorities that are focusing on their individual duties, hardly giving holistic feedbacks from physical, environmental and social aspects.

Fortunately, the SPC pilot project is the overture to knead all these authorities together, since the SPC concerns various disciplines such as drainage, roads, traffic, gardens and hydrology, as shown in Fig. 4 and Table 5 (MOHURD, 2014). SPC construction is capable of nurturing different disciplines with the idea of coexistence of SPC and UHIM and practically integrate them to systematically construct SPC and mitigate UHI, like technical cooperation and data integration. Furthermore, with the involvement of various departments including development and reform commission, financial, land, and tax authorities, the SPC construction receives enough support in land and funds. The main departments can also accomplish their missions of supervising

professionals and assessing their achievements. Overall, the SPC construction is a valuable process to enable distinct disciplines to tell and listen to different views, which is contributable to the formation of profound policies, regulations and guidelines for both SPC and UHIM.

Nevertheless, the efficiencies of inter-agency collaborations have been also criticised, due to weight differences of different authorities and high complexity in management. Some authorities are reluctant to collaborate because they are not the dominant party in the inter-agency system (Li et al., 2017). The inclusion of UHIM can raise the weights of some authorities for the adoption of diverse UHIM strategies. For example, the departments associated with water affairs may be dominant because of the original nature of UFM, while the weights of gardening, road and traffic can be elevated along with the use of green infrastructure and cool pavement. Connecting SPC construction and UHIM, therefore, can enhance the institutional synergies and encourage each department to exert its role.

3.2.4. Social feasibility

SPC had been an innovative approach to UFM in China. This project is practically conducive to reduce the water influence of people's daily life in aspects of alleviating water damage caused by flooding, reducing the pressure of water scarcity and improving the water quality, thereby improving the health conditions of citizens. Moreover, through SPC construction, the societal inequality caused by water problem can also be reduced. Comparatively, due to the temperature increase in cities, outdoor thermal comfort has been significantly reduced. Moreover, the overheating in cities have improved the mortality and morbidity, especially for low-income families and vulnerable groups (i.e. children and elders) because of their financial restrictions to air-conditioning and high sensitivity to heat stress (Santamouris et al., 2017). UHI effects have more significant influences on low-income families. The UHI has increased cooling load, but these people are poor to pay for the increased energy bills, aggravating the problem of energy poverty (Sakka et al., 2012). Therefore, UHIM becomes an urgent problem of various cities, forming the social foundations to develop co-benefits system for SPC and UHIM.

4. Pathways to co-benefits implementation

SPC opens a 'window of opportunity' for the positive expectations of UHIM. Apart from lowering urban temperature, the SPC shares many techniques with UHIM, which can potentially spur technological innovation. At the very beginning, SPC can cover most economic costs of UHIM. It is expectable that lower marginal cost can effectively promote the combination of SPC and UHIM. Social benefits can enhance citizens' participation and further consolidate governmental policy. However, achieving the synergies of SPC and UHIM, more work should be carried out.

4.1. Challenges to implementing co-benefits

Co-benefits approach is conducive to climate change mitigation and adaption in environmental, social, economic, political/institutional and climate-related dimensions (Mayrhofer and Gupta, 2016). The application of the co-benefits approach has been a fundamental trend in addressing climate change. The essence of simultaneous benefits makes the co-benefits approach applicable and flexible in various fields (Castillo et al., 2007). Nevertheless, the implementation of the co-benefits approach is still limited by several barriers.

- Lack of acknowledgement of two major problems. China has delivered the SPC advocacy from the central government to local governments. Many local governments have formulated plans to construct SPC. However, the SPC philosophy has primarily disseminated among governmental bodies rather than the general public. For UHI phenomenon, it has been only acknowledged among

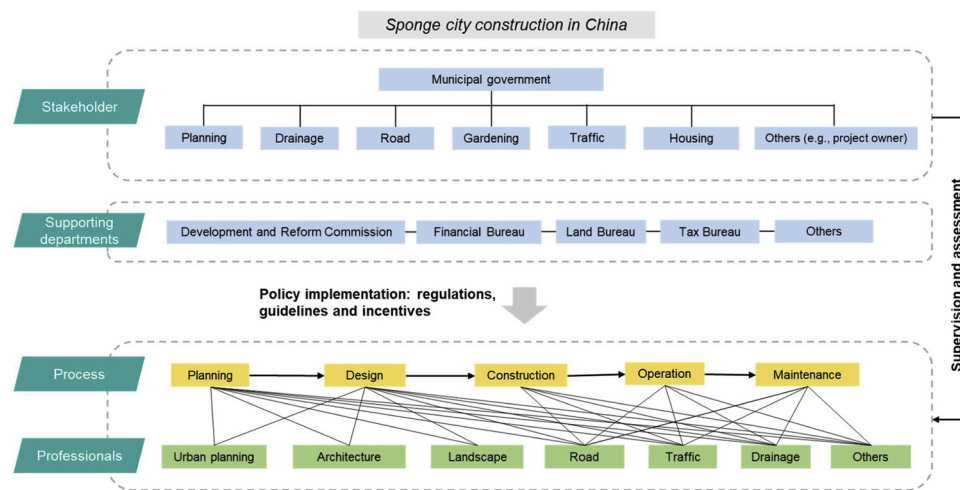


Fig. 4. The inter-agency collaborations during the SPC construction (Revised based on MOHURD, 2014).

a few departments for weather, and disaster prevention and mitigation. Most citizens can recognise temperature increase and adopt some adaptive measures, while there is no technical guideline to cope with UHI effects. Without enough knowledge of SPC and UHIM, citizens can hardly support the implementation of SPC and UHIM.

- Few understandings of the linkages between SPC and UHIM. Co-benefits approach has been mainly proposed to highlight the benefits of climate change mitigation and adaption on the alleviation of air pollution. In this scope, afterwards, co-benefits approach has been further developed into integrative paradigms for air quality, energy, transport, agriculture and economics (Castillo et al., 2007), as well as the framework with five strategical sector including health, mobility, resources, buildings and economy (Floater et al., 2016). However, there are very few cases concentrating on co-benefits approach for addressing two paralleled problems in climate change simultaneously, which means the understandings of the linkages between SPC and UHIM are still insufficient. This study preliminarily shows the environmental, economic, political/institutional and social feasibilities for the co-benefits of SPC and UHIM, while more studies are required to uncover the linkages between SPC and UHIM.

- Lack of information on co-benefits contribution. The implementation of the co-benefits approach can bring social, environmental, economic and political/institutional benefits. This study has only drawn on the foundation for the co-benefits between SPC and UHIM, while what co-benefits approach can conversely contribute SPC and UHIM are still not clear. UHIM has not been implemented, so that co-benefits implementation can benefit UHIM, through the tentative implementation of SPC. Once UHIM would have been implemented, it is essential to further reveal the contribution of co-benefits to SPC construction.
- Weak political/institutional performance. The mitigation and adaption activities of climate change are complex and difficult, so that the implementation of these activities is always led by the government. However, the existing policies for SPC construction issued by the government have been criticised. Meanwhile, although there have been guidelines to distinguish the functions of different departments, for inter-agency cooperation during SPC implementation, it is still difficult to realise the coordination between different governmental departments with different interests. To implement the co-benefits approach, the UHIM will be included, implying more challenges to governmental departments and their cooperation.

Table 5

The responsibility of different government departments in SPC construction.

Governmental departments	Responsibilities
Administration Office Construction	Sponge city construction assessment will be included in the target management of the municipal government. Responsible for the overall planning and coordination of sponge city construction. Take the lead in formulating supporting policies for sponge cities, such as technical regulations for the planning and construction management of sponge cities, and related construction, acceptance standards and norms; Formulate annual targets and supervise and assess the construction of sponge cities by lower-level governments.
Development and Reform Commission	Examine and approve sponge city-related projects at the municipal level; Responsible for annual construction investment plan; study and guide the investment and financing mode of sponge city projects.
Finance	Responsible for the research and formulation of a long-term financial investment mechanism, financial support means and financial subsidy system; Responsible for the annual budget arrangement, municipal fundraising and allocation, financial fund project performance evaluation, etc.
Land Planning	Include sponge city construction requirements into the land transfer program. Compile sponge city special plans; Relative targets should be included in the strategic plan and detailed plans.
Housing	Promote urban old estates renewal according to the requirements of sponge city construction; Maintenance of the sponge city construction related facilities in the newly built communities.
Road Water	Responsible for the management and maintenance of sponge city road and square facilities. Implement the plan of the utilisation of reclaimed water, and carry out the implementation work of black and smelly rivers; Manage and maintain sponge city waterworks facilities.
Gardening and Forestry	Manage and maintain the urban green; Promote the renovation of existing green spaces in accordance with the requirements of sponge city construction.

4.2. Framework of multi-scale stakeholders

Developing the co-benefits of SPC for UHIM covers at least two scopes, namely addressing urban flooding problem and dealing with the urban temperature. It requires the involvement of different professionals, such as urban planners, engineers, designers and manager from different disciplines. At the governmental scale, it involves departments of planning, drainage, road, traffic, forest and gardening, etc. The combination of SPC construction and UHIM may lead to controversies among different stakeholders that have distinct responsibilities and conflicts among different scales from the national to the local. For the improvement of internal governance mechanisms to guarantee the coherency of SPC construction and UHIM, it is essential to respect the significance to establish the framework of multi-scale stakeholders (Gattuso et al., 2018). Under the guidance of multi-scale stakeholders, the relationships (e.g., co-benefits, co-costs, trade-offs, spill-over benefits, ancillary benefits) between UFM and UHIM should be organised and conceptualised, so as to determine an explicit goal of the SPC construction and UHIM. Moreover, in the framework, the responsibilities of different departments and stakeholders should be clarified to realise their coordination.

Fig. 5 presents the pathways to co-benefits implementation among multi-scale stakeholders. First, the multi-scale can be comprehended in a spatial context, as the community level, district level and city level indicated in Fig. 5. As the implementation of co-benefits of SPC and UHIM is complex, it should evolve from community level (niches) to district level (regime) and then city level (landscape). Because of restrictions of material resources, co-benefits of SPC and UHIM can only be achievable at the lowest scale. The successful implementation at community scale will be upscaled to district and city levels, at which time the community can be micro-drivers providing essential functions and performances (He et al., 2018), and motivate private behaviours and public policy (Rotmans et al., 2001). Conversely, the co-benefits implementation in a larger context, such as district and city levels, can provide community-level co-benefits with a stable atmosphere, which means more support, especially the immaterial resources (Bai et al., 2016). From the perspective of co-benefits performance, meanwhile, the influences of SPC and UHIM on urban systems and living environments expand gradually. Community-level co-benefits can be propagated for its performance of UFM and UHIM, followed by better understandings of the co-benefits approach in district and city scopes. The macro context can further drive more societal concerns and private investments for community-level promotion (He et al., 2018). In

another aspect, the multi-scale lies in the two scopes of SPC and UHIM, each of which is in relation to various aspects in techniques, plans, involvers and performances. All these should be balanced when intentionally integrating SPC and UHIM together for simultaneous implementation.

Starting from co-benefits opportunity identification, such as the linkages in various dimensions, the co-benefits approach can be formulated in a community context. Accordingly, the synergistic actions for SPC and UHIM should be determined. Climate change mitigation and adaption strategies are always advocated by government, so that different departments should set their responsibilities, but this should serve for integrated plans and policies. It should be particularly pointed out that public participation should be in the duty of a specific department for propaganda. Afterwards, the co-benefits can be implemented and then quantified and optimised. Overall, the implementation of the co-benefits approach should strictly follow the synergies of multiple functions and the close collaborations among various departments and stakeholders.

Although the pathways to co-benefits implementation have been presented in Fig. 5, more efforts are required to advance co-benefits between SPC and UHIM.

- Developing a synergistic technical system. There are many commonalities among the techniques and performance of SPC and UHIM, but also many differences and problems. To integrate them into a uniform system to intentionally maximise their co-benefits, it is essential to identify these commonalities and further develop a technical database. Afterwards, the performance of these techniques should be assessed, for which purpose determining assessment indicators and tools are required.
- Defining integrative plans and policies. Since current co-benefits system covers SPC and UHIM, it is, therefore, necessary to balance the goals in addressing urban flooding problem and UHI effects. This is determined by the restrictions of material resources and investments. The policies are important to deliver the governmental wills to address these problems, playing a decisive role in the financial system. On the one hand, the government may provide financial incentives to implement pilot projects; On the other hand, governmental policies can affect public actions and private investments.
- Communication among different departments and various stakeholders. Consistent with integrative plans and policies, the responsibilities of each governmental department should be distinguished. Nevertheless, co-benefits implementation cannot be parted

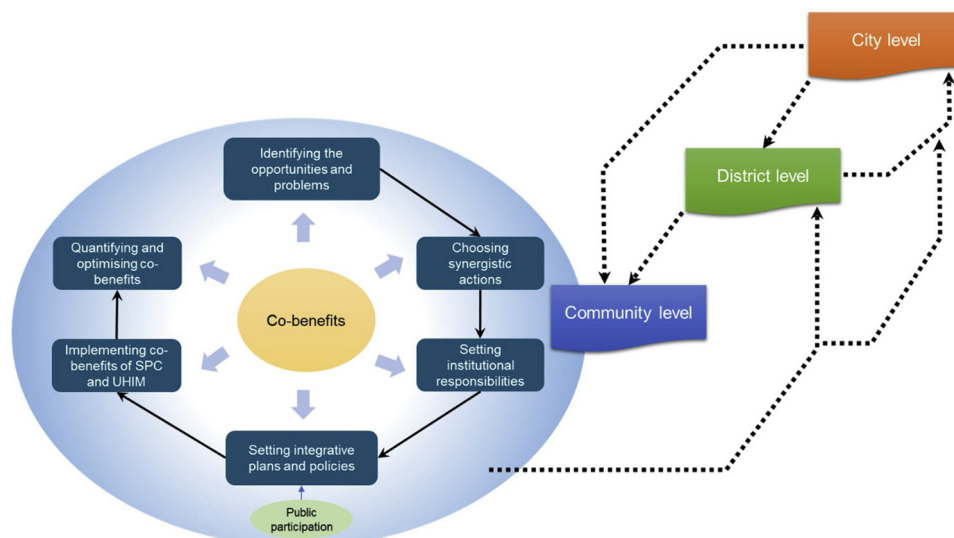


Fig. 5. Pathways to co-benefits implementation among multi-scale stakeholders.

completely due to the internal integrations, so that each government department should integrate collaboratively and communicate timely for a project. Considering the involvement of industrial and private groups, communication should be carried out among governmental departments, industrial and private groups, as well.

- Implementing pilot projects for quantifying and optimising co-benefits approach. To examine the performance of the co-benefits approach for SPC and UHIM, pilot projects should be implemented in practice, so as to provide solid references for assessment and quantification. The co-benefits in various dimensions are mostly in a qualitative pattern. Currently, the planners and decision-makers have not well acknowledged the significance of co-benefits during policy design, becoming difficulties to monetise social benefits (Creutzig and He, 2009). The co-benefits have been criticised for the uncertainties and risks when sacrificing the benefits of a specific project for another one, at which time the ‘win-win’ strategies may be insufficient to address any one of them (Mayrhofer and Gupta, 2016). Therefore, the benefits of SPC construction for UHIM should be quantitatively assessed. Moreover, the integrative assessment models and multicriteria analysis can be optimised through considering multiple simultaneous outcomes for better performance and further upscaling (Ürge-Vorsatz et al., 2014).

5. Conclusions

According to the co-benefits approach, SPC is an opportunity to technically mitigate UHI phenomenon with higher compatibilities in cool pavement and green infrastructures. Although there are some intrinsic discrepancies among understandings of SPC and UHIM towards blue infrastructure, the osmotic pool, wet pond, and regulating pond are essential supplements to urban water bodies, performing their roles in nourishing vegetation and evaporating for cooling in UHIM. SPC pilot projects have already provided the financial foundation for taking the UHIM further. It is an attempt for people in different disciplines to synergistically think about how to mitigate UHI effects, which is conducive to the generation of holistic policies, guidelines and regulations. Furthermore, the inclusion of UHIM can be a driver to public participation in SPC construction, which can consolidate the PPP model for more funds. The weights of different authorities can also be redistributed to promote institutional transitions.

SPC is theoretically a chance, having apparent co-benefits on UHIM. It can be a universal pattern for other countries that have implemented some similar water management concepts such as LID, SUDS, BGC, WSUD and LIDUS, to mitigate UHI via SPC projects. The SPC oriented UHIM can also provide references for other practically implementing projects such as green building, low-carbon eco-city, smart city, forest city and haze treatment for UHIM. The ongoing SPC projects should start to pay attention to the UHI issues since it will be a significant practice to alleviate all professions’ burdens if SPC can well mitigate UHI phenomenon.

Acknowledgement

Authors express great thank to the support from Australian Government Research Training Program.

References

Bai, X., Surveyer, A., Elmqvist, T., Gatzweiler, F.W., Güneralp, B., Parnell, S., et al., 2016. Defining and advancing a systems approach for sustainable cities. *Curr. Opin. Environ. Sustain.* 23, 69–78.

Bain, P.G., Milfont, T.L., Kashima, Y., Bilewicz, M., Doron, G., Garðarsdóttir, R.B., et al., 2016. Co-benefits of addressing climate change can motivate action around the world. *Nat. Clim. Change* 6 (2), 154.

Balbus, J.M., Greenblatt, J.B., Chari, R., Millstein, D., Ebi, K.L., 2014. A wedge-based approach to estimating health co-benefits of climate change mitigation activities in the United States. *Clim. Change* 127 (2), 199–210.

Castillo, C.K., Sanqui, D.C., Ajero, M., Huizenga, C., 2007. The co-benefits of responding

to climate change: status in Asia. Manila: Clean Air Initiative for Asian Cities.

Çelik, S., Retzlaff, W., Morgan, S., Oğuş Binatlı, A., et al., 2010. Energy Evaluation and Economic Impact Analysis of Green Roofs Applied to a Pilot Region in Aegean Coast of Turkey (No. 10/01). Working Papers in Economics.

Chan, F.K.S., Griffiths, J.A., Higgitt, D., Xu, S., Zhu, F., Tang, Y.T., Xu, Y., Thorne, C.R., 2018. “Sponge City” in China—a breakthrough of planning and flood risk management in the urban context. *Land Use Policy*. <https://doi.org/10.1016/j.landusepol.2018.03.005>.

Conway, D., Schipper, E.L.F., 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. *Global Environ. Change* 21 (1), 227–237.

Creutzig, F., He, D., 2009. Climate change mitigation and co-benefits of feasible transport demand policies in Beijing. *Transp. Res. Part D: Transp. Environ.* 14 (2), 120–131.

Emmanuel, R., Loconsole, A., 2015. Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK. *Landscape Urban Plann.* 138, 71–86.

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., et al., 2015. SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage. *Urban Water J.* 12 (7), 525–542.

Floater, G., Heeck, C., Ulterio, M., Mackie, L., Rode, P., Bhardwaj, A., et al., 2016. Co-Benefits of Urban Climate Action: A Framework for Cities. *Economics of Green Cities Programme*. London School of Economics and Political Science, LSE Cities, pp. 1–7.

Gattuso, J.-P., Magnan, A.K., Bopp, L., Cheung, W.W.L., Duarte, C.M., Hinkel, J., Mcleod, E., Micheli, F., Oschlies, A., Williamson, P., Billé, R., Chalastani, V.I., Gates, R.D., Irissou, J.-O., Middelburg, J.J., Pörtner, H.-O., Rau, G.H., 2018. Ocean solutions to address climate change and its effects on marine ecosystems. *Front. Mar. Sci.* 5, 337. <https://doi.org/10.3389/fmars.2018.00337>.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res. Policy* 31 (8–9), 1257–1274.

Harlan, S.L., Ruddell, D.M., 2011. Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Curr. Opin. Environ. Sustain.* 3 (3), 126–134.

He, B.-J., 2018. Potentials of meteorological characteristics and synoptic conditions to mitigate urban heat island effects. *Urban Clim.* 24, 26–33.

He, B.-J., Zhao, D.-X., Zhu, J., Darko, A., Gou, Z.-H., 2018. Promoting and implementing urban sustainability in China: an integration of sustainable initiatives at different urban scales. *Habitat Int.* <https://doi.org/10.1016/j.habitatint.2018.10.001>.

He, B.-J., Zhao, Z.-Q., Shen, L.D., Wang, H.B., Li, L.G., 2019. An approach to examining performances of cool/hot sources in mitigating/enhancing land surface temperature under different temperature backgrounds based on landsat 8 image. *Sustain. Cities Soc.* 44, 416–427.

Henry, A., Frascaria-Lacoste, N., 2012. The green roof dilemma—Discussion of Francis and Lorimer. *J. Environ. Manage.* 104, 91–92.

Herath, H.M.P.I.K., Halwatura, R.U., Jayasinghe, G.Y., 2018. Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy. *Urban For. Urban Green.* 29, 212–222.

Hu, M., Zhang, X., Siu, Y.L., Li, Y., Tanaka, K., Yang, H., Xu, Y., 2018. Flood mitigation by permeable pavements in Chinese sponge city construction. *Water* 10 (2), 172.

IPCC, 2007. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom.

Jia, H., Wang, Z., Zhen, X., Clar, M., Shaw, L.Y., 2017. China’s Sponge City construction: a discussion on technical approaches. *Front. Env. Sci. Eng.* 11, 18. <https://doi.org/10.1007/s11783-017-0984-9>.

Jiang, Y., Zevenbergen, C., Ma, Y., 2018. Urban pluvial flooding and stormwater management: a contemporary review of China’s challenges and “sponge cities” strategy. *Environ. Sci. Policy* 80, 132–143.

Li, X., Li, J., Fang, X., Gong, Y., Wang, W., 2016. Case Studies of the Sponge City Program in China. *World Environmental and Water Resources Congress*, pp. 295–308 2016.

Li, H., Ding, L., Ren, M., Li, C., Wang, H., 2017. Sponge city construction in China: a survey of the challenges and opportunities. *Water* 9 (9), 594.

Liu, J., Zang, C., Tian, S., Liu, J., Yang, H., Jia, S., et al., 2013. Water conservancy projects in China: achievements, challenges and way forward. *Global Environ. Change* 23 (3), 633–643.

Liu, H., Jia, Y., Niu, C., 2017. “Sponge city” concept helps solve China’s urban water problems. *Environ. Earth Sci.* 76 (14), 473. <https://doi.org/10.1007/s12665-017-6652-3>.

Manteghi, G., Remaz, D., 2015. Water bodies an urban microclimate: a review. *Mod. Appl. Sci.* 9 (6), 1.

Mayrhofer, J.P., Gupta, J., 2016. The science and politics of co-benefits in climate policy. *Environ. Sci. Policy* 57, 22–30.

MOHURD, 2014. The Construction Guideline of Sponge City in China – Low Impact Development of Stormwater System(Trail). The Ministry of Housing and Urban-Rural Development of China.

MOHURD, 2015. Promote the Construction of Sponge City, Create a Bright Future for the City. Retrieved at: The Ministry of Housing and Urban-Rural Development of China. http://www.mohurd.gov.cn/jsbld/201505/t20150529_221551.html.

MWR, 2013. Ministry of Water Resources: Bulletin of the First National Census for Water. China Water Conservancy and Hydropower Press.

NDRC, 2017. China’s Policies and Actions to Address Climate Change, 2017 Annual Report. National Development and Reform Commission, pp. 3–4. <http://www.ndrc.gov.cn/gzdt/201710/W020171101318500878867.pdf>.

Nemet, G.F., Holloway, T., Meier, P., 2010. Implications of incorporating air-quality co-benefits into climate change policymaking. *Environ. Res. Lett.* 5 (1), 014007.

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S., 2015. Planning for cooler cities: a framework to prioritise green infrastructure to mitigate

- high temperatures in urban landscapes. *Landscape Urban Plann.* 134, 127–138.
- Peng, L.L., Jim, C.Y., 2015. Economic evaluation of green-roof environmental benefits in the context of climate change: the case of Hong Kong. *Urban For. Urban Green.* 14, 554–561.
- Peng, S., Feng, Z., Liao, H., Huang, B., Peng, S., Zhou, T., 2019. Spatial-temporal pattern of, and driving forces for, urban heat island in China. *Ecological indicators* 96, 127–132.
- Qi, J.D., He, B.J., Wang, M., Zhu, J., Fu, W.C., 2019. Do grey infrastructures always elevate urban temperature? No, utilizing grey infrastructures to mitigate urban heat island effects. *Sustain. Cities Soc.* 46, 101392.
- Rotmans, J., Kemp, R., Van Asselt, M., 2001. More evolution than revolution: transition management in public policy. *foresight* 3 (1), 15–31.
- Sakka, A., Santamouris, M., Livada, I., Nicol, F., Wilson, M., 2012. On the thermal performance of low income housing during heat waves. *Energy Build.* 49, 69–77.
- Santamouris, M., 2014. Cooling the cities—a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Sol. Energy* 103, 682–703.
- Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., Paolini, R., et al., 2017. Passive and active cooling for the outdoor built environment—Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. *Sol. Energy* 154, 14–33.
- Silva, H., Fillpot, B.S., 2018. Modeling nexus of urban heat island mitigation strategies with electricity/power usage and consumer costs: a case study for Phoenix, Arizona, USA. *Theor. Appl. Climatol.* 131 (1–2), 661–669.
- Ürge-Vorsatz, D., Herrero, S.T., Dubash, N.K., Lecocq, F., 2014. Measuring the co-benefits of climate change mitigation. *Annu. Rev. Environ. Resour.* 39, 549–582.
- Wang, Y., Sun, M., Song, B., 2017. Public perceptions of and willingness to pay for sponge city initiatives in China. *Resour. Conserv. Recycl.* 122, 11–20.
- Wang, J., Meng, Q., Zhang, L., Zhang, Y., He, B.J., Zheng, S., Santamouris, M., 2019. Impacts of the water absorption capability on the evaporative cooling effect of pervious paving materials. *Build. Environ.* 151, 187–197.
- World Bank, 2011. Guide to Climate Change Adaptation in Cities. The International Bank for Reconstruction and Development / The World Bank.
- Xia, J., Zhang, Y., Xiong, L., He, S., Wang, L., Yu, Z., 2017. Opportunities and challenges of the Sponge City construction related to urban water issues in China. *Sci. China-Earth Sci.* 60, 652–658.
- Yang, K., Yu, Z., Luo, Y., Yang, Y., Zhao Zhou, L.X., 2017. Spatial and temporal variations in the relationship between lake water surface temperatures and water quality—A case study of Dianchi Lake. *Sci. Total Environ.* 624, 859–871.
- Yang, Q., Huang, X., Tang, Q., 2019. The footprint of urban heat island effect in 302 Chinese cities: temporal trends and associated factors. *Sci. Total Environ.* 655, 652–662.
- Zhao, Z.Q., He, B.J., Li, L.G., Wang, H.B., Darko, A., 2017. Profile and concentric zonal analysis of relationships between land use/land cover and land surface temperature: case study of Shenyang, China. *Energy Build.* 155, 282–295.
- Zhao, L., Oppenheimer, M., Zhu, Q., Baldwin, J.W., Ebi, K.L., Bou-Zeid, E., et al., 2018. Interactions between urban heat islands and heat waves. *Environ. Res. Lett.* 13 (3), 034003.
- Zhou, D., Zhao, S., Liu, S., Zhang, L., Zhu, C., 2014. Surface urban heat island in China's 32 major cities: spatial patterns and drivers. *Remote Sens. Environ.* 152, 51–61.